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Hard X-ray Variability of the Brightest Swift/BAT AGN

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Variability is one of the hallmarks of Active Galactic Nuclei. The Burst Alert Telescope onboard of *Swift*, with its homogeneous coverage of the sky is a formidable tool to study variability at hard X-rays. We present here the analysis of the 1-month binned *Swift*/BAT lightcurves of the 20 brightest Active Galactic Nuclei in the hard X-ray sky. The sample consists of 2 blazars, 3 radio galaxies, 6 Seyfert 1/1.5s, 8 Seyfert 2s and 1 Narrow Line Seyfert 1. We found that all the objects show variability, and most of them have a value of the fractional root mean squared variability amplitude of $F_{\rm var} \sim 0.2-0.3$. We did not find any significant correlation of $F_{\rm var}$ with the column density or the luminosity in our sample.

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1. Introduction

Active Galactic Nuclei (AGN) are amongst the most luminous X-ray sources in the sky. AGN are thought to be powered by accretion onto supermassive black holes (Rees, 1984), with their X-ray emission probably originating in a hot corona sandwiching the accretion disk (Haardt & Maraschi, 1991) in radio-quiet objects, and in the jet in radio-loud AGN (e.g., Boettcher 2010). Variability is one of the key features of AGN, and it was found to be significative in the X-ray band already in early observations of nearby Seyfert galaxies (Sy) performed by *Ariel V* (Marshall et al., 1981). The X-ray variability of AGN is aperiodic, and their power spectral density distribution (PSD) can be normally described with a broken power law, with indices ranging between -1 and -2 (McHardy & Czerny, 1987).

The Burst Alert Telescope (BAT) onboard of *Swift* (Barthelmy et al., 2005) scans continuously the whole sky in the 14–195 keV energy range, and is thus an extremely well suited instrument for studying AGN variability at hard X-rays. Here we report a study of the hard X-ray variability of a small sample of AGN. The sample consists of the 20 brightest AGN detected by *Swift*/BAT, of these 2 are blazars, 2 narrow-line radio galaxies (NLRG), 1 broad-line radio galaxy (BLRG), 6 Seyfert 1/1.5s, 8 Seyfert 2s and 1 Narrow Line Seyfert 1 (NLS1). The 1-month binned light curves have been taken from the NASA *Swift*/BAT 58 months catalog[1] (Baumgartner et al., 2011).

2. Variability estimators

A way to estimate the variability is through the fractional root mean squared (rms) variability amplitude $F_{\rm var}$ (Edelson et al., 1990), defined as

$$F_{\rm var} = \sqrt{\frac{S^2 - \overline{\sigma^2_{err}}}{\overline{x}^2}}. \tag{2.1}$$

Where the sample variance S^2 is given by

$$S^2 = \frac{1}{N-1}\sum_{i=1}^{N}(x_i - \overline{x})^2, \tag{2.2}$$

while the mean square error $\overline{\sigma^2_{err}}$ by

$$\overline{\sigma^2_{err}} = \frac{1}{N}\sum_{i=1}^{N}\sigma^2_{err,i}. \tag{2.3}$$

The error of $F_{\rm var}$ is given by

$$err(F_{\rm var}) = \sqrt{\left(\sqrt{\frac{1}{2N}}\cdot\frac{\overline{\sigma^2_{err}}}{\overline{x}^2 F_{\rm var}}\right)^2 + \left(\sqrt{\frac{\overline{\sigma^2_{err}}}{N}}\cdot\frac{1}{\overline{x}}\right)^2}. \tag{2.4}$$

In the following we will use $F_{\rm var}$ to characterize the variability of the objects in our sample.

[1]http://swift.gsfc.nasa.gov/docs/swift/results/bs58mon/

Table 1: Properties of the sources of our sample: (1) detection significances, (2) luminosities in the 14–195 keV energy range, (3) fractional rms variability amplitudes on a timescale of 30 days, (4) hydrogen column densities.

Source	(1) Det. Significance $[\sigma]$	(2) $\log L_{14-195\,\mathrm{keV}}$ $[\mathrm{erg\,s^{-1}}]$	(3) $\mathrm{F_{var}}$ (30-days)	(4) N_{H} $[\mathrm{cm^{-2}}]$	Type
Cen A	428.7	44.01	0.399 ± 0.002	12^{a}	NLRG
NGC 4151	275.0	44.11	0.280 ± 0.004	6.9^{b}	Sy 1.5
3C 273	156.8	47.47	0.31 ± 0.01	0.5^{b}	Blazar
NGC 4388	110.7	44.64	0.31 ± 0.01	27^{b}	Sy 2
Mrk 421	109.5	45.46	0.96 ± 0.01	0.1^{b}	Blazar
Circinus Galaxy	101.7	43.09	0.13 ± 0.01	360^{b}	Sy 2
IC 4329A	101.1	45.22	0.19 ± 0.02	0.4^{b}	Sy 1
NGC 2110	98.1	44.60	0.32 ± 0.01	4.3^{c}	Sy2
NGC 5506	95.0	44.31	0.27 ± 0.02	3.4^{c}	NLS1
MCG−05−23−016	90.4	44.50	0.21 ± 0.01	1.6^{c}	Sy2
IGR J21247+5058	83.3	45.25	0.31 ± 0.01	0.6^{b}	BLRG
NGC 4945	76.1	43.37	0.35 ± 0.02	400^{b}	Sy2
Mrk 348	70.4	44.91	0.28 ± 0.02	30^{c}	Sy2
NGC 3783	68.7	44.60	0.26 ± 0.02	0.1^{c}	Sy1.5
NGC 4507	64.6	44.77	0.29 ± 0.02	29^{c}	Sy 2
NGC 3516	62.3	44.33	0.30 ± 0.02	4^{c}	Sy 1.5
NGC 7172	60.1	44.46	$0.35 \pm 0.04^{*}$	9^{c}	Sy 2
NGC 3227	56.2	43.57	0.16 ± 0.21	6.8^{c}	Sy 1.5
Cyg A	54.0	46.01	0.34 ± 0.02	11^{b}	NLRG
MCG +08−11−011	49.0	45.09	0.35 ± 0.03	0.2^{c}	Sy 1.5
Crab	7496	–	0.0215 ± 0.0004	–	–

Notes. [a] Beckman et al. (2011), [b] Beckmann et al. (2009) and references therein,
[c] Ricci et al. (2011) and ref. therein. * "Flare" of January 2008 removed.

3. Results

In Table 1 are listed the values of the fractional rms variability amplitude of the objects of our sample, and as a check, the value obtained from the light curve of the Crab ($F_{\mathrm{var}} \sim 0.02$). The value of the Crab can be associated to the systematic error of the *Swift*/BAT data. In Fig. 1, we show the light curves of 6 out of the 20 sources of our sample. All the sources of our sample show hard X-ray variability on the time-scale of one month. As it can also be seen from Fig. 2, the value of the fractional rms variability amplitude is $F_{\mathrm{var}} \sim 0.2-0.3$ for most of the objects of the sample, with the average value being $\overline{F_{\mathrm{var}}} = 0.32$. The blazar Mrk 421 shows a much stronger variability ($F_{\mathrm{var}} \sim 0.96$) than the average value of the sample. Amongst the radio-quiet NGC 7172 is the most variable, with a value of $F_{\mathrm{var}} \sim 0.48$. This is due to what would appear to be a flare, registered

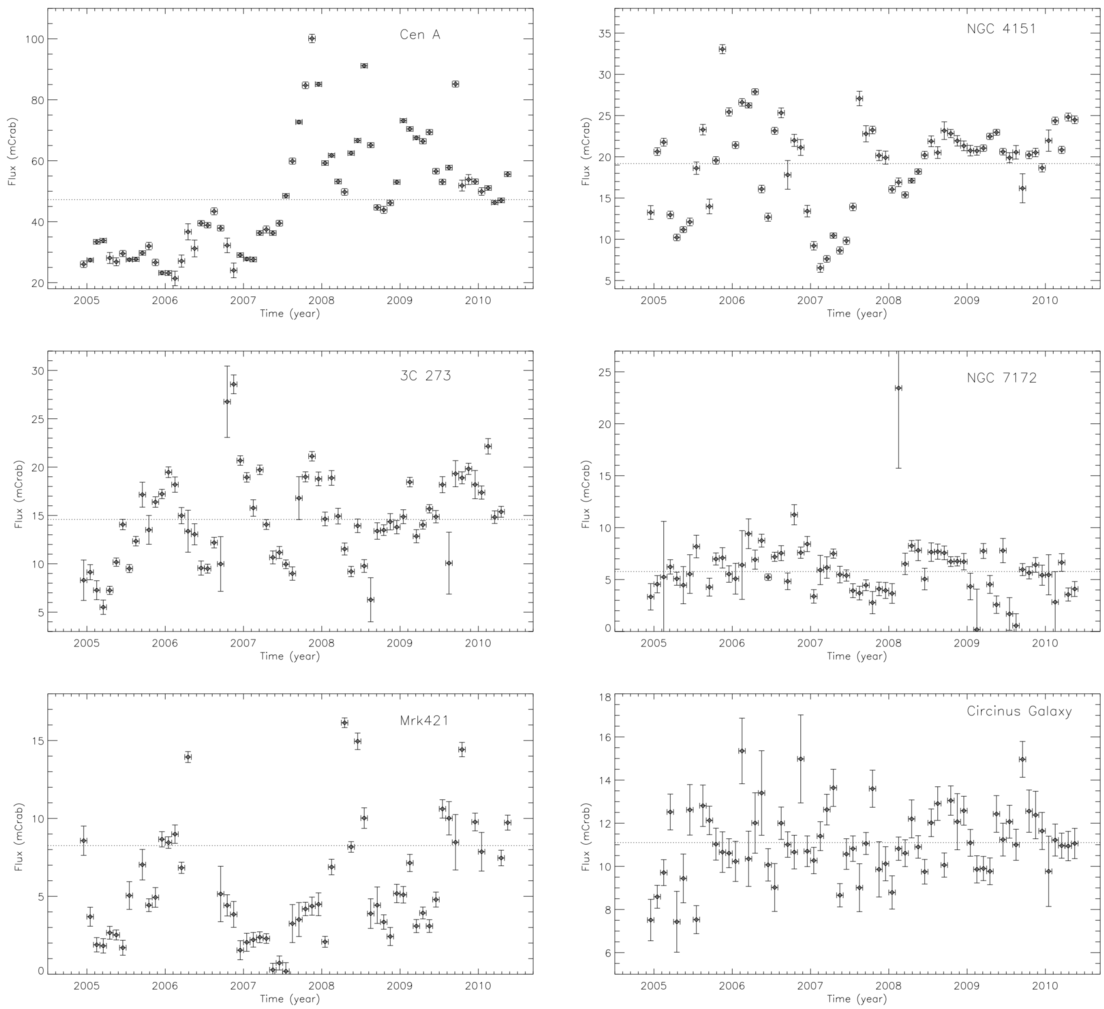

Figure 1: *Swift/BAT* 30-days binned light curves in the 14–195 keV band. The dotted horizontal lines represent the average value for each object.

in January 2008. Excluding this outlier point NGC 7172 shows a variability consistent with the average of our sample ($F_{\rm var} = 0.35 \pm 0.04$). At the other end of the distribution, the Compton-thick Seyfert 2 Circinus Galaxy and the Seyfert 1 IC 4329A show the smallest amounts of variability ($F_{\rm var} \sim 0.13$ and $F_{\rm var} \sim 0.19$, respectively). The low value of $F_{\rm var}$ of Circinus Galaxy is very likely related to the reflection-dominated nature of its hard X-ray spectrum.

4. Variability vs Luminosity and Column density

An inverse correlation between the variability amplitude in the X-rays and the X-ray luminosity of AGN was found by (Barr et al., 1986)using *EXOSAT* data. More recently, Beckmann et al. (2007) studied the hard X-ray variability of the 44 brightest AGN detected by BAT after 9 months of operations, and found that possibly this anti-correlation is extended to the hard X-ray band (see also Soldi et al., 2010). They also found a possible correlation between the hydrogen column density $N_{\rm H}$ and the variability amplitude. We investigated the existence of these two correlations in our

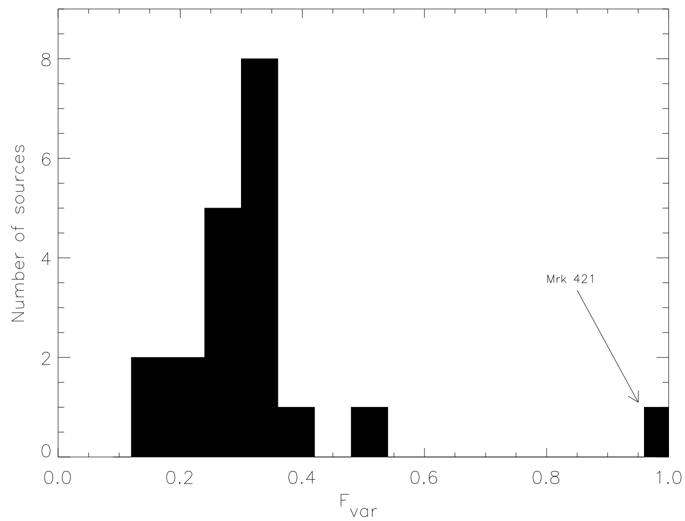

Figure 2: Distribution of the fractional rms variability amplitude for the 20 sources of our sample.

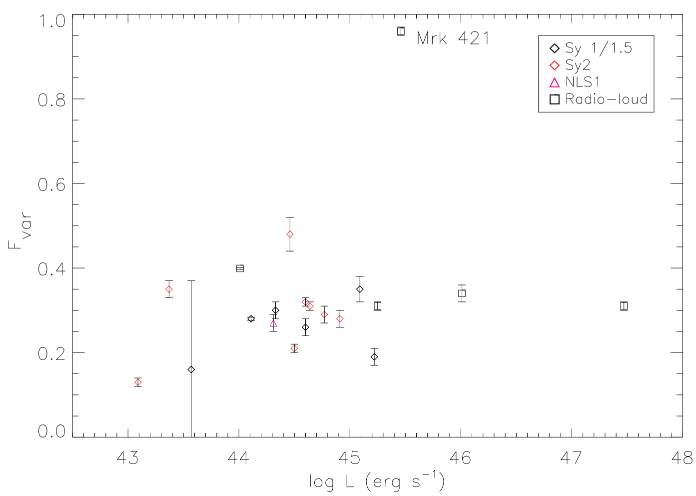

Figure 3: $F_{\rm var}$ versus luminosity for the sources of our sample.

sample (see Figs. 3 and 4). The variability amplitudes in our sample are confined in a small range of values, and no correlation with other parameters is evident. A Spearman rank test gives a correlation coefficient between $F_{\rm var}$ and the luminosity of $r_s = 0.27$, while it is $r_s = 0$ between $F_{\rm var}$ and $N_{\rm H}$. These values correspond to a probability of correlation of 78% in the first case, and of 0% in the second case. Similar results are obtained also considering Mrk 421 as an outlier. No significant correlation is found also dividing the sample in three categories (Sy 1/1.5, Sy2, radio-loud). The lack of correlations might be due to the limited sample we used, and further studies are needed to better probe it.

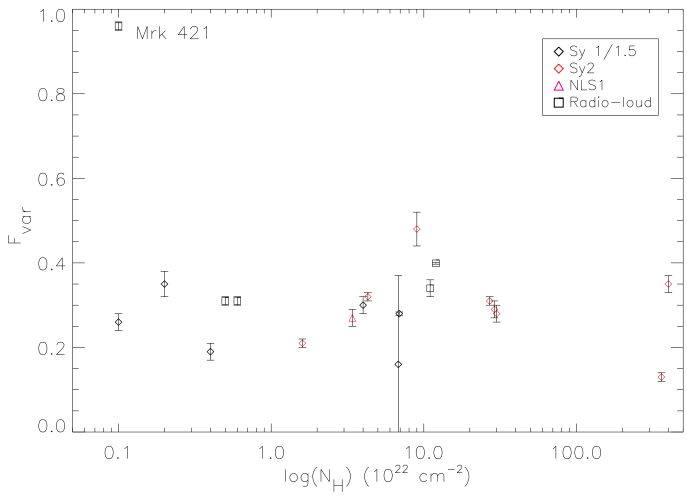

Figure 4: $F_{\rm var}$ versus hydrogen column density for the sources of our sample.

5. Conclusions

Studying the 1-month binned *Swift*/BAT light-curves of the 20 brightest objects after 58 months of observations, we found that all the objects in our sample show variability, ranging between $F_{\rm var} = 0.13$ and $F_{\rm var} = 0.96$, for Circinus galaxy and Mrk 421, respectively. The average value of the variability amplitude if $F_{\rm var} \sim 0.3$. We did not find any significant correlation of the variability amplitude with the luminosity and the hydrogen column density.

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